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(54) GENERATION OF MODULATED CARRIER WAVES FOR PHASE OR PHASE-AMPLITUDE SHIFT KEYING

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of 190 Strand, London, WC2R 1DU, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to the generation of modulated carrier waves for phase shift keying (PSK) data transmission systems.

When data signals are passed through a band limited channel, e.g. a telephone channel, their frequency spectrum has to be translated to the passband of the channel by modulation, and shaped according to the channel characteristics in order to minimise intersymbol interference.

One method of modulation extensively used in data transmission is a phase-shift keying, in which the phase of a carrier wave is changed once in every symbol period (signal element), according to the incoming data stream. PSK can be used as a pure phase modulation, or combined with amplitude modulation. The number of discrete phases the carrier wave can assume depends on the encoding used. Usual values are 2, 4, 8 etc.

A convenient way of generating the modulated carrier wave in a phase-shift keyed transmitter is to generate a square wave carrier at the appropriate phase for each signal element to be transmitted, and pass this square wave through a shaping filter to obtain a band limited line signal. The square wave carrier can be generated by simple logic circuitry.

The overall spectral shaping of the signal when subsequently demodulated in the receiver is determined by the specturm of the square wave carrier and the frequency characteristics of all filters in the transmission path. Optimum spectral shaping which is independent of the transmitted phase can only be obtained if the spectrum of the square wave carrier is identical for every transmitted phase of the carrier. However, due to 'foldover' effect, in general the spectrum of the square wave carrier within the passband of the channel (around the carrier frequency) depends on the relative phase of the carrier to the signal element. This is due to the frequency spectrum of the square wave carrier being wide relative to the carrier frequency and it extends below zero frequency. Since physical networks do not distinguish between positive and negative frequencies, the frequency components below zero are folded over about zero frequency into the positive frequencies. The way in which the foldover components combine with the other depends on the carrier phase relative to the signal element.

Conventional methods of eliminating foldover include double modulation, and baseband filtering followed by modulation. In double modulation the carrier is modulated by the data signal at a high frequency such that the modulated spectrum diminishes at positive frequencies, then the modulated spectrum is bandlimited by filtering to the channel bandwidth and translated down to channel frequencies by a second modulation, followed by lowpass filtering. When baseband filtering is employed, first the data signal is bandlimited by filtering, then the carrier is modulated by the bandlimited data signal, the modulation again being followed by filtering. Both these methods are costly compared with the generation of the modulated carrier by logic circuitry followed by bandpass filtering.

According to the present invention there is provided a method of generating modulated carrier waves for phase or phase-amplitude shift keying data transmission systems comprising the steps of generating two square waves in quadrature, generating

the inverse waveforms of the two square waves and utilising any of the four waves so generated either singly or in combination, the waves in any such combination having either the same amplitude or different amplitudes, the utilisation being such that any two carrier waves chosen to represent two conditions of data signal elements to be transmitted by the system have mirror images of each other either in the time domain or the amplitude domain or both and that the duration of the signal elements is a mutliple of a quarter of the carrier wave cycle, said multiple having a numerical value of not less than 5.

Embodiments of the invention will now be described with reference to the drawings accompanying the provisional specification, in which:-

Figure 1 shows two quadrature waves,

Figure 2 shows a vector representation of a four-phase system,

Figure 3 shows a vector representation of a sixteen-phase system,

Figure 4 shows the generation of four of the sixteen carrier phases of Figure 3,

Figures 5-7 show the relationship between signal element duration and carrier cycle duration,

Figures 8a-8c show a practical realisation of the invention for a four-phase system.

Figure 9 shows an alternative realisation for a four-phase system,

Figure 10 shows an example of generating transmitted carrier wave sections in a sixteen-phase system, and

Figure 11 shows examples of different pulse sequences having identical frequency spectra.

The subject of this invention is a method of generating the modulated carrier wave by logic circuitry, which at the same time provides optimum spectral shaping at any modulated phase, with the condition that the duration of the signal element is a multiple of the quarter of the carrier cycle.

If the above condition holds, as is most often the case in data transmission, according to this invention it is always possible to find a carrier phase relative to the signal element such that the signal spectrum is independent of the phase modulation, for any signal constellation, i.e. any number of transmitted phases and amplitudes. Foldover is not eliminated by this method, but the spectrum being constant, its effect can be compensated for by the appropriate shaping of the bandpass filter following the carrier generation.

The method of generating the optimum relative phase is described below.

Figure 1 shows two quadrature square waves A and B.

If the number of phases transmitted is two or four and they are equally spaced, then one or both of these waves, respectively, and their inverses, can directly be used as carrier waves. Figure 2 shows the vector representation of a four-phase system.

Any other signal constellation can be generated by the analogue addition of two quadrature square waves at the appropriate signals and amplitudes. An example for a 16-point constallation (combined PM and AM) as shown in Figures 3 and 4. The relative amplitudes of the quadrature carriers are ± 1 and ± 3. Figure 3 shows the vector representation of the 16 points together with the quadrature carriers A and B. Figure 4 shows the generation of four of the sixteen carrier phases (those in the first quadrant) obtained by the addition of waves A and B. It can be seen from this example that any carrier phase can be generated by the addition of two quadrature waves. The spectrum of the combined wave is the sum of the spectra of the two waves added, apart from some cancellation at frequencies away from carrier frequency, therefore it is only necessary to ensure that the spectra of the two quadrature waves are identical, in order to obtain a similar spectrum for any modulated phase. This can be achieved according to this invention, as described below if the duration of each signal element is a multiple of the quarter of the carrier cycle.

There are two distinct cases:

1. the duration of the signal element is an odd multiple of the quarter of the carrier cycle.

2. the duration of the signal element is an even multiple of the quarter of the carrier cycle.

In the first case, transitions of the two quadrature carriers, alternately, have to occur at the edges of the signal elements. An example is shown in Figure 5, where the length of the signal element is $1\frac{1}{4}$ times the length of the carrier cycle. It can be seen that all quadrature wave sections generated within a signal element have the same shape and differ only in their directions and signs. It will be shown later that such signals possess identical spectra.

In the second case, if transitions of one of the quadrature carriers occurred at the edges of the signal elements, mid-points of the other carrier would occur at the same instants. An example is shown in Figure 6 for a signal element duration of $1\frac{1}{2}$ times the length of the carrier cycle. The two quadrature carriers in this case would have different spectra and optimum spectral shaping could not be achieved simultaneously for all transmitted carrier phases.

The correct phasing of the quadrature carriers relative to the signal element is shown in Figure 7. Here the carrier phase is chosen such that the edges of the signal elements occur half way between transitions of

the two quadrature carriers. Again, the shapes of the carrier wave sections within a signal element are the same. Although their directions and signs are different, the spectra of all carrier wave sections are identical, as will be shown later.

An example of the practical realisation of the invention is shown in Figure 8 for a 4-phase system and carrier wave sections as in Figure 5. Figure 8a is a timing diagram, showing the relative phases of carriers A and B and the symbol rate (signal element), together with the generating clock. The negative transitions of the signal "Symbol Rate" separate the signal elements from each other. Figure 8b shows a circuit diagram for the generation of these waveforms. Bistables A and B from a Johnson counter. Their outputs are the two carrier waves A and B, respectively. The other three bistables generate the symbol rate. The encoder includes all circuits performing coding in the transmitter e.g. scrambler and differential encoder. Outputs b_1 and b_2 of the encoder determine the phase to be transmitted, according to Figure 8c. If b_1 and b_2 have the same logic state, carrier A is transmitted. If b_1 and b_2 are different, carrier B is transmitted. The inversion of both A and B is determined by the state of b_1. If b_1 = '1', the carriers are inverted in an exclusive or gate. Next, the signal is clamped by a diode in order to make the signal amplitude independent of integrated circuit parameters, and the d.c. component is removed by passing the signal through a capacitor. Finally the signal is amplified if necessary, and the unwanted frequency components are removed and the spectrum is shaped by a bandpass filter.

Figure 9 shows another example of carrier and symbol rate generation, when the carrier waves are as in Figure 7. The rest of the circuitry for a 4-phase system is the same as in Figure 8b.

Figure 10 shows an example of generating transmitted carrier wave sections in a 16-phase system, by the analogue addition of two quadrature carriers as e.g. in Figure 4. Figure 10a shows the circuit diagram and Figure 10b the four-bit encoding of the 16-phase signal constellation. Bit b_1 determines the sign of carrier B, b_2 determines the signal of carrier A, b_3 determines the magnitude of carrier B and b_4 determines the magnitude of carrier A. The necessary inversions are performed by exclusive-or gates. The required signal components are selected by analogue switches and added in a summing amplifier, followed by a bandpass filter to remove unwanted frequency components and to shape the transmitted spectrum.

The invention defines the phase of two quadrature carriers relative to the signal element, in order to obtain identical spectra for all modulated carrier phases, so that simple digital generation of the transmitted carrier is possible.

If the length of the signal element is an odd multiple of the quarter of the carrier cycle, then transitions of the quadrature carriers must coincide with the edges of the signal elements.

If the length of the signal element is an even multiple of the quarter of the carrier cycle, then the mid-points between the transitions of the two quadrature waves must coincide with the edges of the signal elements (i.e. the edges of the signal elements occur $\frac{1}{8}$ of a carrier cycle before or after the edges of the quadrature carriers).

At any other relative phase between the quadrature carriers and the signal elements, the spectrum of the modulated carrier depends on the modulated phase and optimum spectral shaping cannot be achieved for every modulated phase by simple means.

It can be shown that ractangular pulse sequences which differ only in their directions and signs, (e.g. those shown in Figure 5 and Figure 7) possess identical frequency spectra.

An example of three such waves is shown in Figure 11, representing carrier waves within a signal element. Each of these can be decomposed into a sum of an odd and an even function, relative to the centre of the signal element. This is also shown in Figure 11. It can be seen that the only difference between the corresponding functions (odd or even) is in their signs. Since the Fourier transform of an odd function consists only of sine terms, and that of an even function consists only of cosine terms, the frequency spectrum of the composite wave is calculated as $F(w) = \sqrt{F_1(w) + (w)^2}$

where $F_1(w)$ and $F_2(w)$ are the spectra of the odd and even functions, respectively. $F(w)$ is independent of the signs of $F_1(w)$ and $F_2(w)$, therefore the spectra of the composite waves are identical.

WHAT WE CLAIM IS:-

1. A method of generating modulated carrier waves for -phase or phase-amplitude shift keying data transmission systems comprising the steps of generating two square waves in quadrature, generating the inverse waveforms of the two square waves and utilising any of the four waves so generated either singly or in combination, the waves in any such combination having either the same amplitude or different amplitudes, the utilisation being such that any two carrier waves chosen to represent two conditions of data signal elements to be transmitted by the system have mirror images of each other either in the time domain or the amplitude domain or both and that the duration of the

signal element is a multiple of a quarter of the carrier wave cycle, said multiple having a numerical value of not less than 5.

2. A method according to claim 1 wherein said multiple has a numerical value of 6.

3. Apparatus for generating modulated carrier waves for phase or phase-amplitude shift keying data transmission systems comprising means for generating two square waves in quadrature, means for generating the inverse waveforms of the two square waves, and logic means for selecting any of the four waves so generated either singly or in combination, said waves having either the same or different amplitudes, the selection being such that any two of the waves chosen to represent two conditions of data signal elements to be transmitted by the system have mirror images of each other either in the time domain or the amplitude domain or both and that the duration of the signal elements is a multiple of a quarter of the carrier wave cycle, said multiple having a numerical value of not less than 5.

4. Apparatus according to claim 3 wherein the means for generating the two square waves comprises a source of clock pulses, a pair of bistables connected to form a Johnson counter driven by said clock pulses, each bistable generating the inverse waveforms of said square waves comprises logic means responsive to data signals from an encoder to invert the output from one or both said bistables when said inverse waveforms are required to convey said data signals.

5. Apparatus according to claim 4 including a further set of bistable elements connected to form a second counter driven by said clock pulses, said second counter being arranged to produce output signals the frequency of which is a multiple of a quarter of the carrier wave cycle, said output signals being applied to the encoder to determine the duration of the signal elements.

6. Apparatus according to claim 3, 4 or 5 wherein said multiple has a numerical value of 6.

7. Apparatus according to claim 4 or 5 including alternative attenuating means for square wave output or the inverse waveform thereof and further logic means responsive to further data signals from the encoder to select alternative amplitudes of the selected waveforms.

8. Apparatus for generating modulated carrier waves for phase or phase-amplitude shift keying data transmission systems substantially as described with reference to the drawings accompanying the provisional specification.

9. A method of generating modulated carrier waves for phase or phase-modulated shift keying data transmission systems substantially as described with reference to the drawings accompanying the provisional specification.

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Agent for the Applicants

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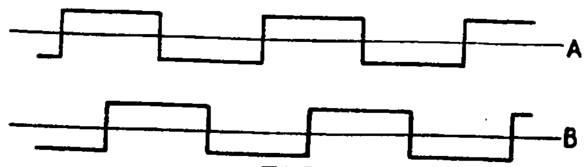


FIG.1

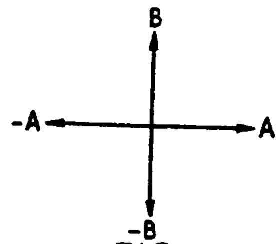


FIG.2

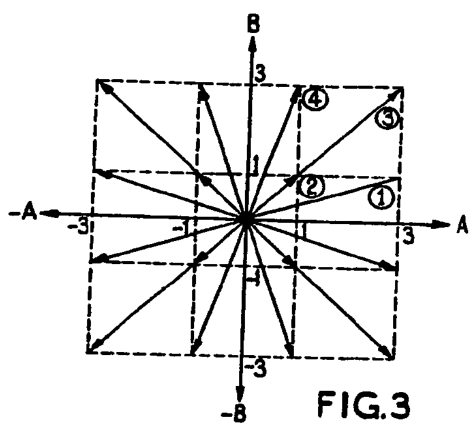


FIG.3

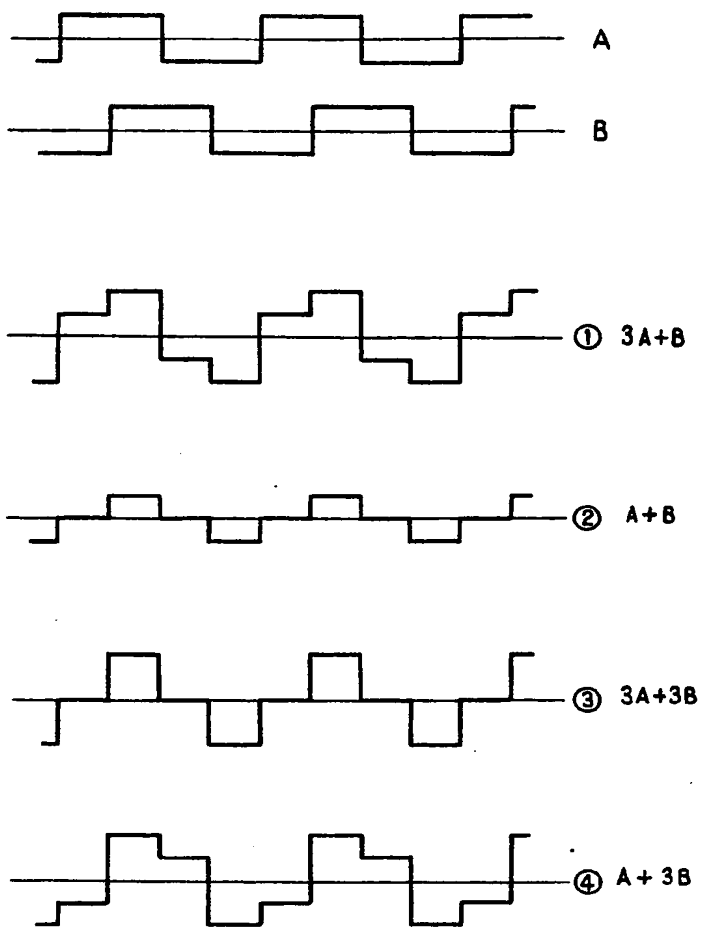


FIG.4

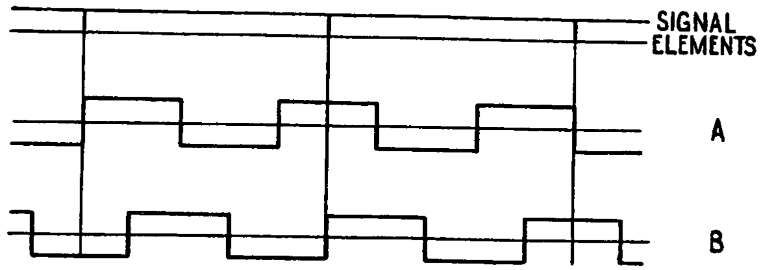


FIG.5

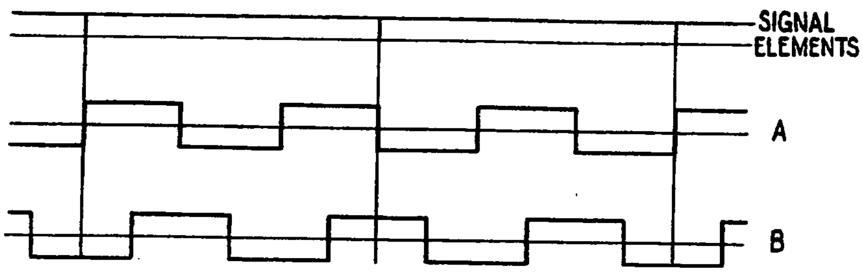


FIG.6

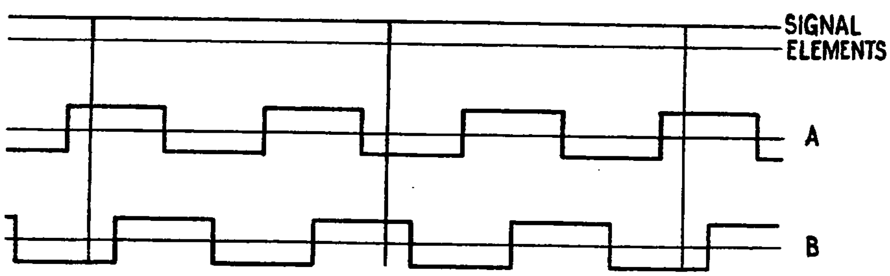


FIG.7

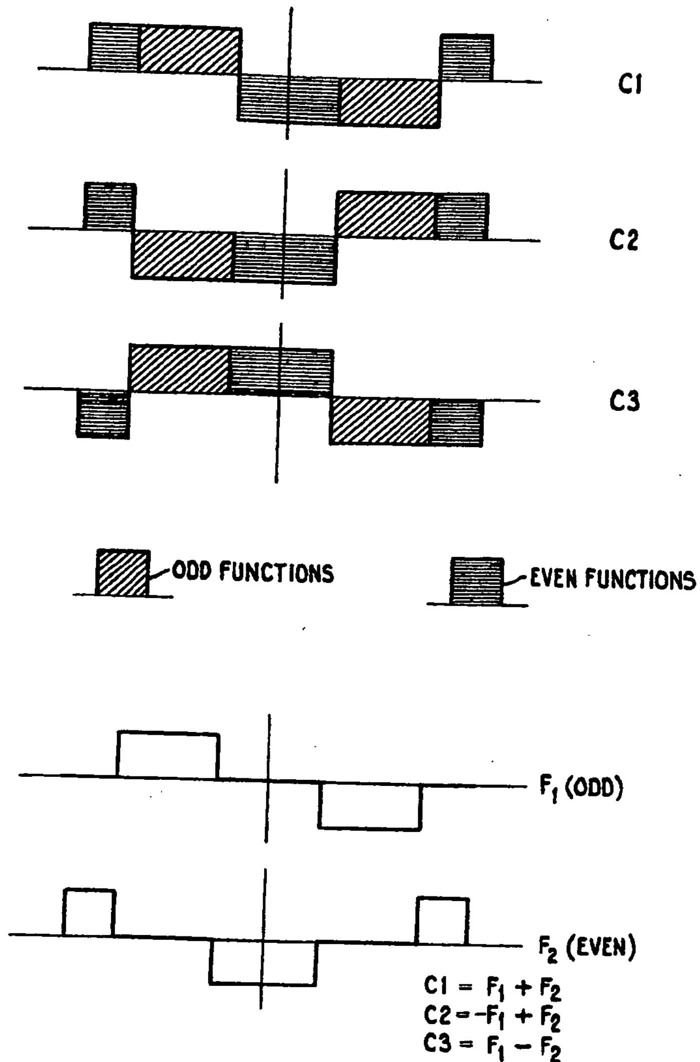

C1
C2
C3
ODD FUNCTIONS
EVEN FUNCTIONS
F_1 (ODD)
F_2 (EVEN)
$C1 = F_1 + F_2$
$C2 = -F_1 + F_2$
$C3 = F_1 - F_2$

FIG.11

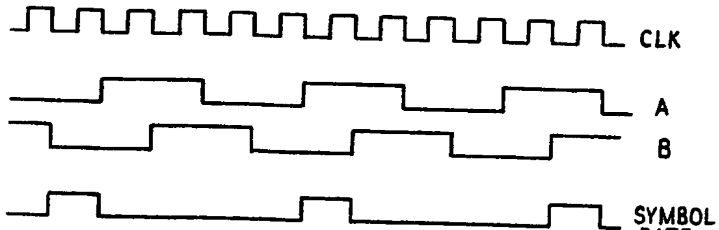


FIG.8a

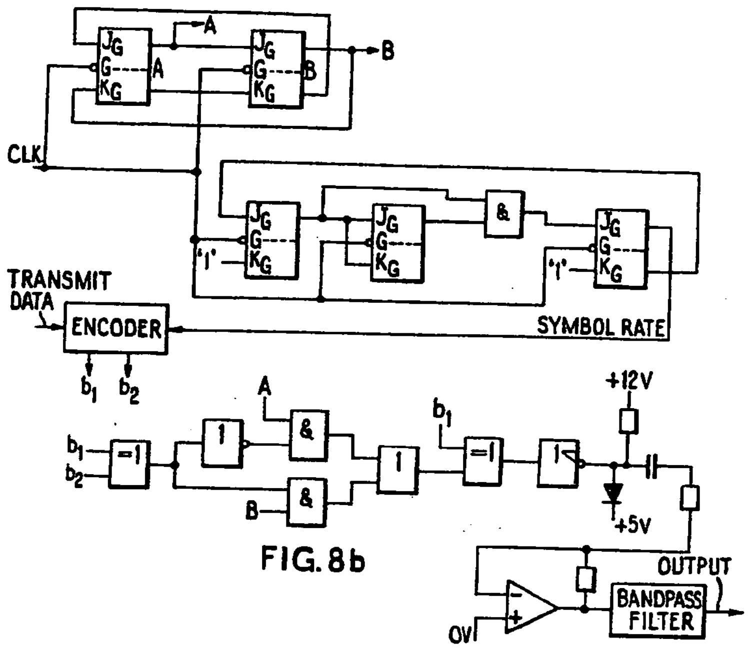


FIG.8b

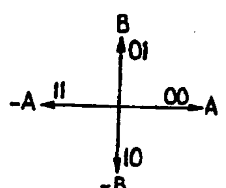


FIG.8c

	b_1	b_2
A	0	0
B	0	1
-A	1	1
-B	1	0

FIG.8

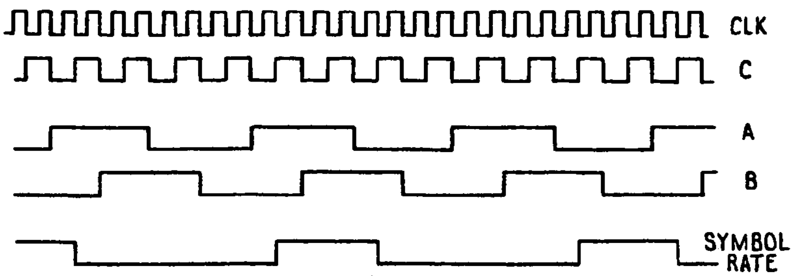


FIG. 9a

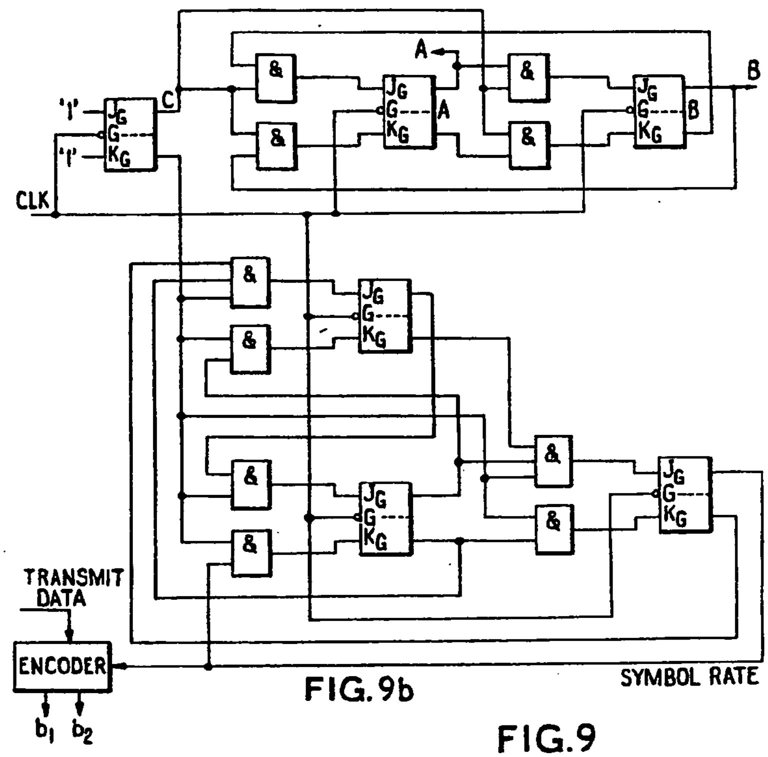


FIG. 9b

FIG. 9

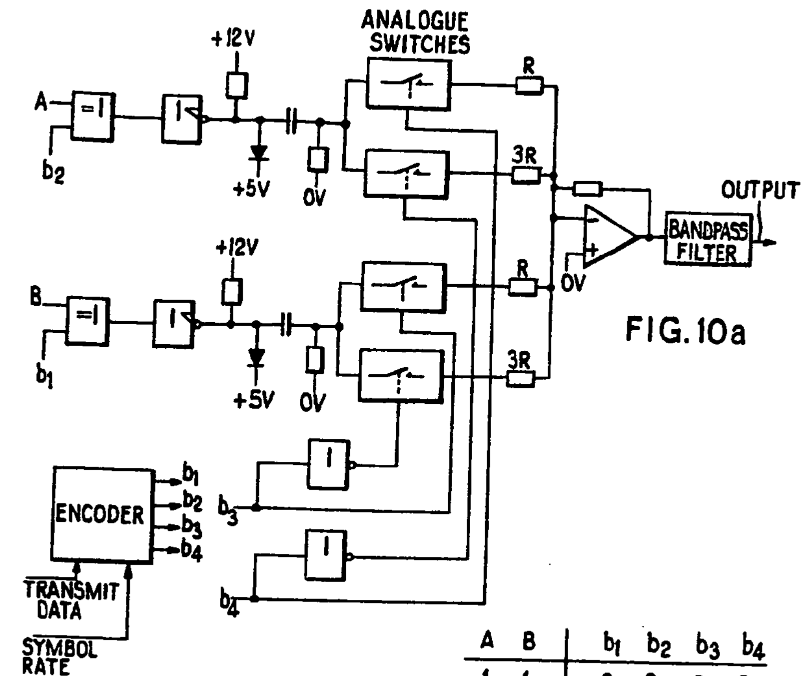
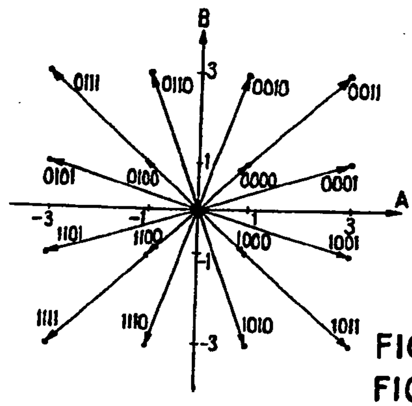


FIG. 10a



A	B	b_1	b_2	b_3	b_4
1	1	0	0	0	0
3	1	0	0	0	1
3	3	0	0	1	1
1	3	0	0	1	0
-1	1	0	1	0	0
-3	1	0	1	0	1
-3	3	0	1	1	1
-1	3	0	1	1	0
-1	-1	1	1	0	0
-3	-1	1	1	0	1
-3	-3	1	1	1	1
-1	-3	1	1	1	0
1	-1	1	0	0	0
3	-1	1	0	0	1
3	-3	1	0	1	1
1	-3	1	0	1	0

FIG. 10b

FIG. 10